

Adaptrum WSD Prototype ATSC Sensitivity Measurement Report

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1. Introduction

We report a measurement made on Adaptrum WSD prototype to determine its ATSC signal sensitivity. The Adaptrum WSD prototype consists of a TV-band RF transceiver board that converts RF signal to/from baseband and an FPGA board where baseband signal processing algorithms are implemented.

Adaptrum's ATSC sensing algorithm looks for the unique time-domain signature of ATSC signal to determine its presence. The default sensing time is approximately 37 seconds per TV channel. We believe this sensing time is appropriate for TV-band white space devices given TV programs are usually on/off for hours. The algorithm has the flexibility to increase or decrease the sensing time for improved or reduced sensitivity. Under default sensing parameter setting (37 second sensing time per TV channel), we report an ATSC sensitivity of -119.5 dBm (100% success detection rate) with false detection probability 0.001 on TV Channel 21 and -118.5 dBm on Channel 59. In the following, we will first discuss false detection and a false detection measurement performed to determine the proper sensing threshold. We then discuss the ATSC sensitivity measurement and its results.

2. False detection measurement

Most detection problems involve a tradeoff between false detection probability (false alarm rate) and loss detection probability. To determine the presence of a target signal, a detection metric (computed from the received signal) is compared with a threshold. The signal presence is considered positive when the metric is above the threshold and negative otherwise. A fair comparison between two detection methods regarding their loss detection performance is only possible when both of them are set to achieve the same false detection probability. This becomes obvious when considering a hypothetical detection method that always calls signal presence positive without doing any actual signal detection. Since detection positive is always called, the loss detection probability is zero. But the false detection probability is one and the utility of detection method is zero.

One potential problem with pilot-tone based ATSC sensing is false detection. Since the decision is solely based on locating a tone at a fixed frequency, any spurious tones that happen to be at that frequency location will trigger false detection. Even with careful design, spurs are usually hard to avoid in a wide-band tunable RF front-end, e.g. due to mixing of LO or signal harmonics.

Another mechanism that can cause false pilot tones is signal intermodulation as illustrated in Figure 1. Signal intermodulation is induced by RF chain nonlinearity. All the nonlinear components (e.g. amplifiers and mixers) in the RF chain before the channel filter (e.g. the 44 MHz SAW filters used by most TV tuners) can contribute to the intermodulation product. Referring to Figure 1, when two strong DTV channels and the target channel are evenly spaced at distance $N \times 6$ MHz where $N = 1, 2, \dots$,

intermodulation between the two DTV signals will result in a false pilot tone in the target channel. Such channel arrangement may easily happen in practice.

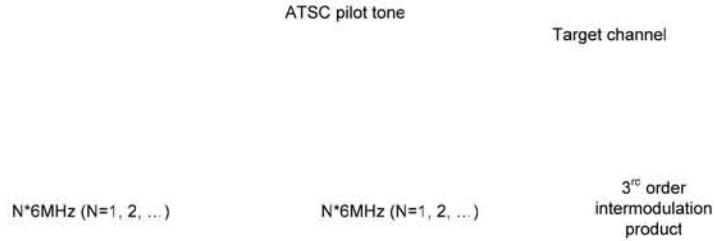


Figure 1: Illustration of false pilot tone due to intermodulation product between DTV signals.

Adaptrum's ATSC sensing algorithm looks for a unique ATSC time-domain signal pattern with built-in randomness. The chance of a spurious signal reproducing such pattern is extremely small, eliminating the possibility of false detection due to spurious signals. The unique signal pattern is searched in time-domain using a matched correlation pattern. The length of the pattern (in number of signal samples) determines the correlation gain over per sample signal SNR. As a further advantage, since Adaptrum's time-domain sensing effectively uses the entire 6 MHz ATSC signal spectrum, it is robust against narrowband, frequency selective fading which may cause problems for pilot-tone based approach.

The correlation output is compared against a threshold for signal detection. As the input signal level decreases well below the noise level, the margin between the correlation output peak and noise floor is diminishing. It is important to choose the correct threshold level in order to optimize both the false detection and loss detection performance. Such threshold is determined by finding a minimum threshold value that can provide certain target false detection probability. Note that the lower the threshold, the higher the false detection probability.

We establish the threshold through the following false detection probability measurement in which we repeat a large number of ATSC signal detections on an input white noise signal and measure the number of false detections at different threshold levels. Note that in our algorithm, the correlation output is normalized by its own power. As a result, the absolute input power level of the white noise signal doesn't have effect on the measurement result.

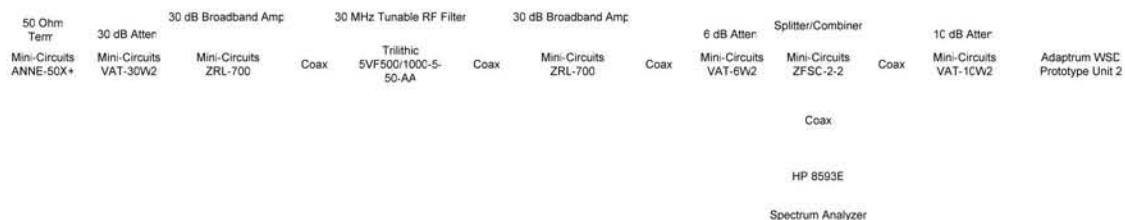


Figure 2: White noise false detection measurement setup.

For the noise source, we use a Mini-Circuits 30 dB broadband (250-700 MHz) low-noise amplifier. The input of the amplifier is terminated so that only thermal noise will be amplified. The output from the amplifier is filtered by an RF filter tuned to a

center frequency of 575 MHz with approximately 30 MHz passband bandwidth. A second 30 dB broadband amplifier will further amplify the passband signal before the WSD receiver.

Considering all the amplifications and attenuations, the noise power seen by the WSD receiver over the 6 MHz signal bandwidth is approximately $-106 + (30 + 30 - 6 - 3 - 10) = -65$ dBm. Since the measurement is not conducted in a screen room, we want to have a reasonably strong noise input to the receiver (as discussed above, input level has no effect on the measurement result) to ensure any over-the-air signal pick-up through the cables or open parts of the system has negligible impact on the measurement accuracy. Note further that we choose Channel 31 (575 MHz center) for the measurement because over-the-air TV signal on the channel is very weak at the measurement location.

A total of 2816 signal detections are performed on the noise input using the above setup. The threshold is chosen so that there are 3 false detections out of all 2816 detections or a false detection probability of approximately 0.001. The same threshold will be used for the loss detection measurement.

3. Loss detection measurement



Figure 3: ATSC sensitivity measurement setup.

Figure 3 shows the loss detection measurement setup. The source ATSC signal is generated using an Agilent E4438C Vector Signal Generator. The baseband ATSC signal waveform is created using Agilent Signal Studio for Digital Video. The waveform is then downloaded to the signal generator, which up-converts the baseband signal to the desired TV channel. Figure 4 shows an example signal spectrum from E4438C received by the WSD receiver.

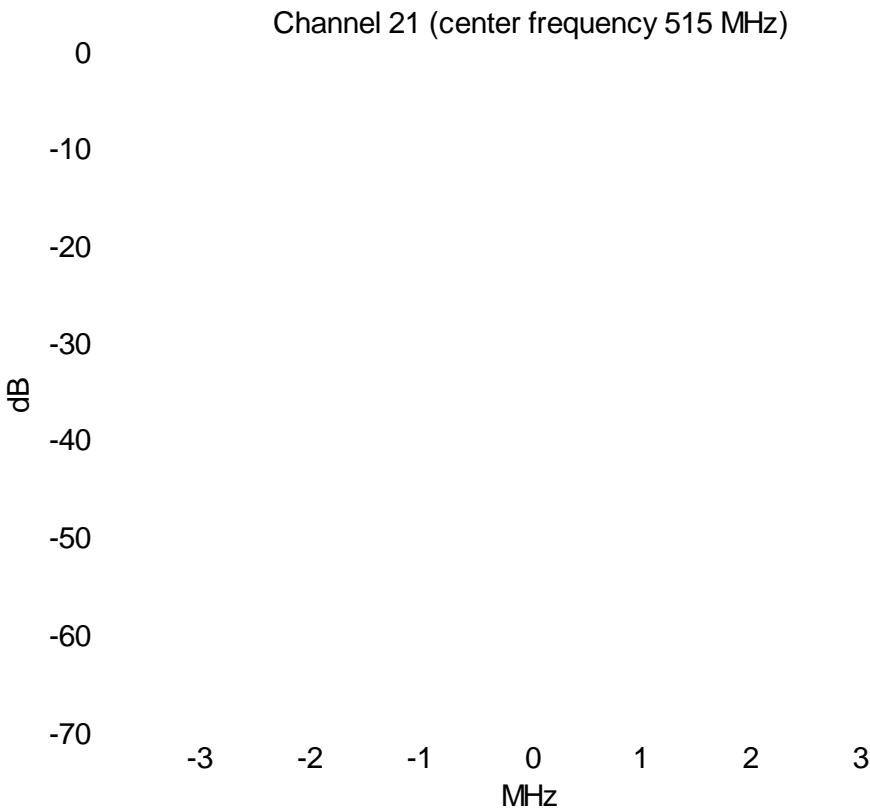


Figure 4: Received ATSC signal spectrum from E4438C.

Since the measurement is not conducted in a screen room, we need to make sure over-the-air signal pick-up through the cable doesn't affect the measurement results. In order to achieve this, we maintain a reasonable signal power in the coaxial cable connecting the signal source and the WSD receiver and we choose a TV channel where over-the-air TV signal is weak at the measurement location.

Referring to Figure 3, the total attenuation from the E4438C to the WSD receiver is approximately 60 dB. Sensitivity measurement will be performed at a WSD input signal level around -120 dBm or the output signal level from the E4438C around -60 dBm and the signal level in the coaxial cable around -70 dBm. We conduct the sensitivity measurement on TV channels 21 (515 MHz center) and 59 (743 MHz center) where the measured over-the-air TV signals are weak.

We use the Rohde & Schwarz wide-band power sensor NRP-Z11 for signal level calibration. We first measure the signal output level directly from the E4438C, i.e. at "Signal Level Measuring Point 1" in Figure 3. With a high input signal from the E4438C, we also measure the signal level at "Signal Level Measuring Point 2". The difference between measured signal levels at these two locations gives the total attenuation through the attenuators and cable assembly. The following table shows the total attenuations for Channel 21 and 59.

Signal loss through attenuators and cable assembly

Channel 21	60.95 dB
Channel 59	60.97 dB

Table 1: Measured total attenuations from E4438C to WSD receiver for Channel 21 and 59.

Table 2 and Table 3 show the sensitivity measurement results for Channel 21 and Channel 59 respectively. At each signal level, a total of 256 trials are performed and the number of successful detections are counted and divided by 256 to give the successful detection rate.

The last row of each table shows the measurement result when the E4438C is turned off, while the rest of the measurement setup is unchanged. The results serve as sanity checks to see whether 1) over-the-air signal pick-up is a problem and 2) the threshold is properly set to achieve the very low false detection rate, i.e. 0.001, as discussed previously. The successful detection rate will floor above 0 if the above two conditions are not met.

E4438C output signal level (dBm)	Signal level seen by WSD prototype (dBm)	Successful detection rate
-58	-118.95	256/256
-58.5	-119.45	256/256
-59	-119.95	240/256
-59.5	-120.45	131/256
-60	-120.95	31/256
-60.5	-121.45	9/256
-61	-121.95	2/256
-INF	-INF	0/256

Table 2: Channel 21 (515 MHz) measurement results.

E4438C output signal level (dBm)	Signal level seen by WSD prototype (dBm)	Successful detection rate
-57	-117.97	256/256
-57.5	-118.47	256/256
-58	-118.97	250/256
-58.5	-119.47	178/256
-59	-119.97	72/256
-59.5	-120.47	11/256
-60	-120.97	5/256
-60.5	-121.47	3/256
-INF	-INF	0/256

Table 3: Channel 59 (743 MHz) measurement results.

Figure 5 plots the measured sensitivity curves using the data in Table 2 and Table 3. Figure 6 shows some lab pictures of the measurement setup.

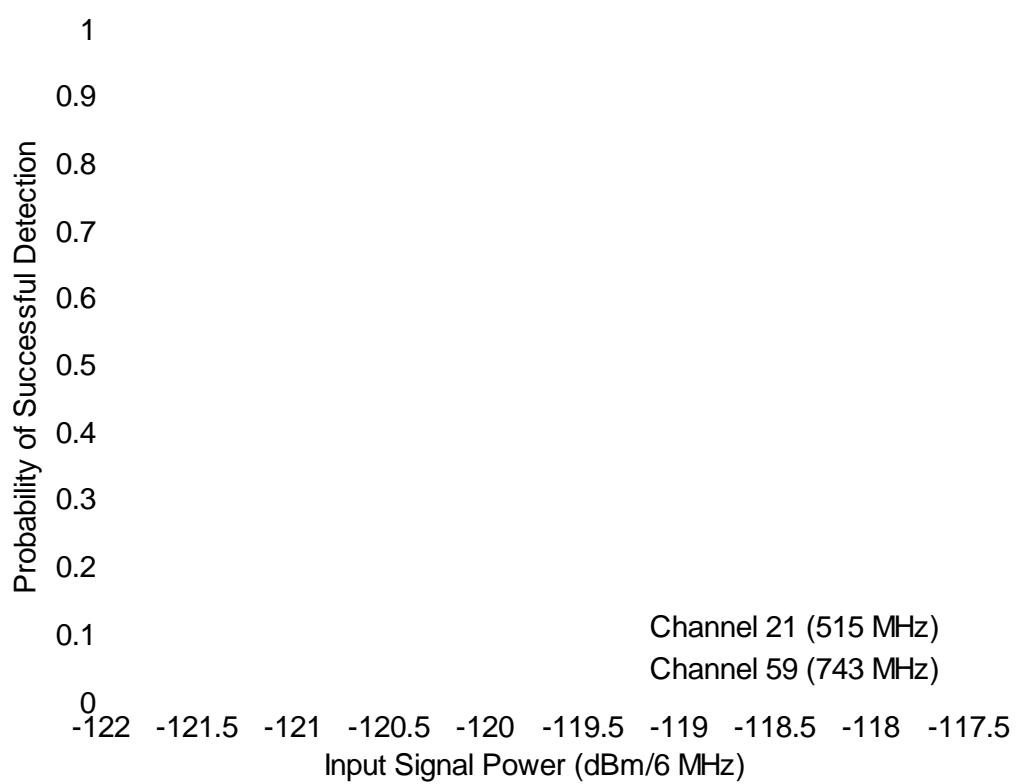


Figure 5: Measured ATSC sensitivity curves on TV Channel 21 and Channel 59.

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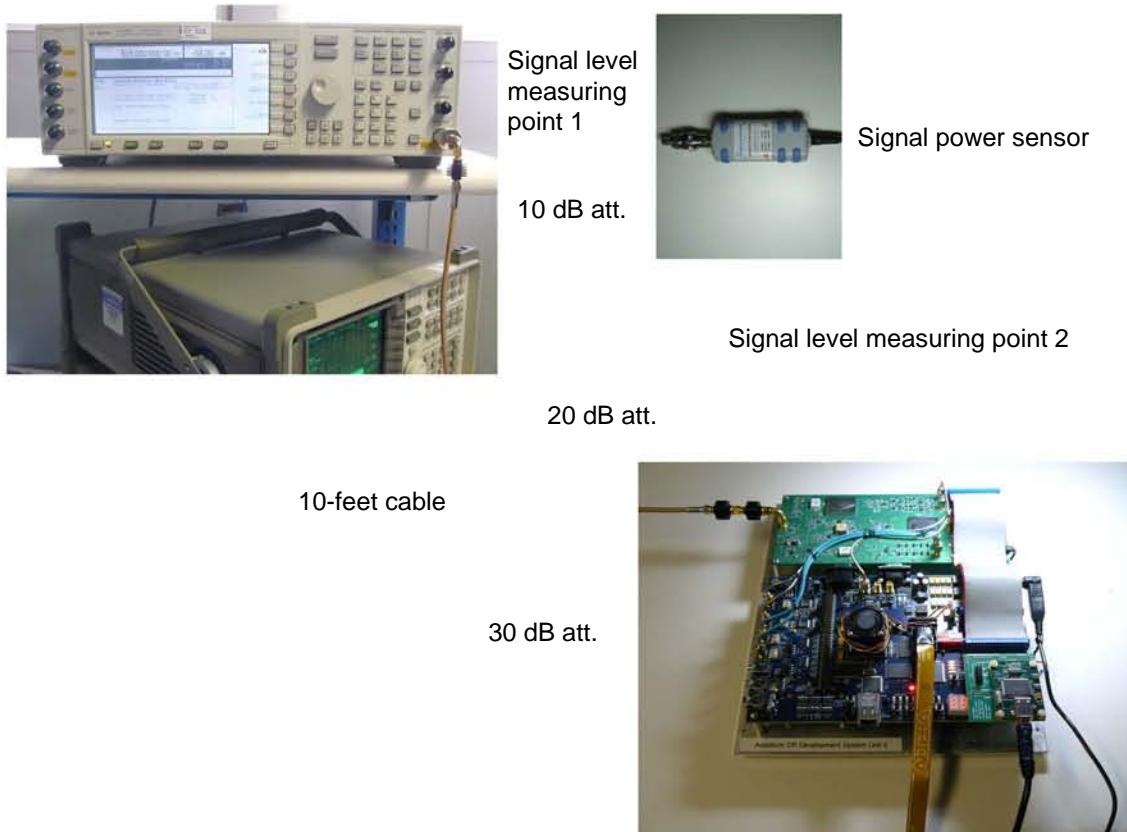


Figure 6: ATSC sensitivity measurement lab pictures.